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Influence of plant density and sowing methods on growth and soil nutrient dynamics in maize under Malwa Region

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Abstract
The present investigation titled "Influence of Plant Density and Sowing Methods on Growth and Soil Nutrient Dynamics in Maize under Malwa Region". The present experiment was conducted at Research Farm, under Mandsaur University, Mandsaur (Madhya Pradesh). Mandsaur (Madhya Pradesh) which is situated at latitude 24^0C 4'36.61''N, longitude $75^0$4'9.46'' E and at an altitude of 442.16 meters above the mean sea level. The experiment involved two main plot treatments: B_1 for flat bed sowing and B_2 for raised bed sowing. There were four sub-plot treatments based on spacing: S_1 for broadcasting, S_2 for 30×25 cm spacing, S_3 for 45×25 cm spacing, and S_4 for 60×25 cm spacing. The treatment combinations were as follows: T_1: Flat bed + Broadcasting (B_1S_1), T_2: Flat bed + 30×25 cm spacing (B_1S_2), T_3: Flat bed + 45×25 cm spacing (B_1S_3), T_4: Flat bed + 60×25 cm spacing (B_1S_4), T_5: Raised bed + Broadcasting (B_2S_1), T_6: Raised bed + 30×25 cm spacing (B_2S_2), T_7: Raised bed + 45×25 cm spacing (B_2S_3) andT_8: Raised bed + 60×25 cm spacing (B_2S_4). There were eight treatments in total, and the experiment was conducted in 24 plots. The gross plot size 4.0 × 5.0 = 20 m^2 and net plot size was 3.5 ×4.5 = 15.75 m^2. The gross plot area was calculated to be 383 m^2. The seed rate used for the experiment was 25 kg per hectare.
Raised bed sowing consistently outperformed flat bed across most parameters, including plant height (55.23 cm, 50.15 cm at 30 DAS), plant gross weight (5.72kg/m² and 3.88 kg/m²), and cob yield (39.68 q/ha and 33.00 q/ha). Among spacing treatments, wider spacing of 60×25 cm recorded the highest gross weight (5.72 kg/m²) and nutrient availability (N: 285.5 kg/ha, P: 25.3 kg/ha, K: 236.4 kg/ha). The interaction of raised bed sowing with 60×25 cm spacing (B_2S_4) resulted in superior growth rate (RGR: 0.055 g g^{-1} day^{-1}), highest gross weight (6.30 kg/m²), nutrient content (N: 292.5 kg/ha, P: 26.5 kg/ha, K: 242.0 kg/ha), and cob yield (42.1 q/ha). Test weight was highest in raised bed with 45×25 cm spacing (228 g) and lowest under flat bed with broadcasting (200 g). Raised bed sowing accelerated silking (60.11 days) compared to flat bed (62.32 days), with widest spacing (60×25 cm) further reducing time to 58.95 days. Soil quality improved under raised bed with lower EC (0.39 dS/m), slightly lower pH (7.12), and higher organic carbon (0.48%). Economically, the highest Benefit-Cost (B:C) ratio was observed under (1.94) T_8 B_2S_4 (Raised bed + 60×25 cm spacing), indicating the best return on investment under the tested conditions. The study concludes that raised bed sowing combined with wider spacing B_2S_4 (Raised bed + 60×25 cm spacing) optimizes maize growth, yield, soil nutrient status, and profitability under Malwa agroclimatic conditions.

Keywords: Flat bed, growth, maize, malwa, raise bed, spacing and sowing

Introduction
Maize (*Zea mays* L.) is a vital cereal crop globally, known for its adaptability and high productivity. It belongs to the Poaceae family and is characterized as a diploid, C_4 photosynthetic plant with a chromosome number of 2n = 20 [7]. Maize has a fibrous root system and is cultivated annually across diverse agro-climatic zones [9]. In India's Malwa region, maize is predominantly grown during the *Kharif* season, benefiting from the region's black cotton and loamy soils and the monsoon rainfall [6]. This crop serves as an important source of carbohydrates and proteins, and is used not only for human consumption but also as livestock feed and raw material in various industries, including biofuels and starch production [1]. The nutritional composition of maize typically includes 60 to 70% carbohydrates, 8 to 10% protein, and essential vitamins such as thiamine and niacin [3].

India is one of the leading maize producers globally, ranking among the top five countries in terms of both area under cultivation and total production. According to the latest data, the world's largest maize producer is the United States, followed by China, Brazil, Argentina, and India [13]. In the 2023–24 cropping season, maize was cultivated on around 108.87 lakh hectares in India, reflecting a rise from 105.24 lakh hectares in the preceding year. Notably, over 78.8% of this area—approximately 85.79 lakh hectares was under Kharif maize cultivation, underscoring its dominance during the monsoon season [13].

Among the many factors influencing maize productivity, plant spacing and sowing techniques are crucial. Proper spacing helps the crop access sunlight, nutrients, and water efficiently by minimizing competition among plants [5]. It also improves air circulation within the canopy, reducing the risk of disease. Different sowing methods, such as flat sowing, ridge and furrow, and broad bed furrow (BBF), play a significant role in conserving soil moisture and supporting healthy root growth, which is particularly important under the varying rainfall patterns experienced in the Malwa region [6].

Despite significant advances in maize cultivation, the Malwa region still faces challenges such as inconsistent rainfall, suboptimal plant spacing, and traditional sowing practices that limit the crop's full yield potential. Many farmers rely on conventional methods that do not optimize plant population or moisture conservation, leading to lower growth efficiency and reduced grain output.

Optimizing sowing practices and plant density can lead to better crop morphology, including plant height, leaf area, and biomass accumulation, which directly impact grain yield. In the Malwa region, adopting suitable spacing and sowing techniques is essential for achieving stable and enhanced maize yields, especially considering the challenges posed by fluctuating rainfall and soil moisture availability.

Addressing these challenges with a focused and positive strategy can empower farmers to increase maize productivity sustainably, contributing to food security and rural livelihoods in the Malwa region. This research will help bridge the knowledge gap and facilitate the adoption of improved agronomic practices that are both economically viable and environmentally sustainable.

Materials and Methods

The present investigation titled "Influence of Plant Density and Sowing Methods on Growth and Soil Nutrient Dynamics in Maize under Malwa Region". The present experiment was conducted at Research Farm, under Mandsaur University, Mandsaur (Madhya Pradesh). Mandsaur which is situated at latitude 24 ^{0}C 4'36.61''N, longitude 75^{0}4'9.46'' E and at an altitude of 442.16 meters above the mean sea level. The experiment involved two main plot treatments: B_1 for flat bed sowing and B_2 for raised bed sowing. There were four sub-plot treatments based on spacing: S_1 for broadcasting, S_2 for 30×25 cm spacing, S_3 for 45×25 cm spacing, and S_4 for 60×25 cm spacing. The treatment combinations were as follows: T_1: Flat bed + Broadcasting (B_1S_1), T_2: Flat bed + 30×25 cm spacing (B_1S_2), T_3: Flat bed + 45×25 cm spacing (B_1S_3), T_4: Flat bed + 60×25 cm spacing (B_1S_4), T_5: Raised bed + Broadcasting (B_2S_1), T_6: Raised bed + 30×25 cm spacing (B_2S_2), T_7: Raised bed + 45×25 cm spacing (B_2S_3) andT_8: Raised bed + 60×25 cm spacing (B_2S_4). The experiment was laid out using a split plot design with three replications. There were eight treatments in total, and the experiment was conducted in 24 plots. The gross plot size 4.0 × 5.0 = 20 m^2 and net plot size was 3.5 ×4.5 = 15.75 m^2. The gross plot area was calculated to be 383 m^2. The seed rate used for the experiment was 25 kg per hectare.

Results and Discussion

Plant Population (5 Tagged Plants per Plot)

Data on plant population at 30 Days after sowing (DAS), based on 5 tagged plants per plot as presented in Table 1**,** illustrate the effects of sowing methods (flat bed and raised bed) and different spacing treatments (broadcasting and row spacing) on early plant establishment in maize (*Zea mays*). Notable variations in plant population were observed due to both main and interaction effects of the treatments. Some previously studies also in line with our study as per [4, 6] in Maize.

Main Effect of Sowing Methods

Plant population recorded at 30 DAS was marginally higher under the flat bed method (B_1), with an average of (80.83) plants per 5 tagged plants per plot. In comparison, the raised bed method (B_2) showed a slightly lower average plant population of (77.20). These results suggest that the flat bed method was slightly more favorable for early plant establishment under the given field conditions. The present results coincides with those of [6, 8] in Maize.

Main Effect of Spacing

Among the different spacing treatments, the highest plant population at 30 DAS was observed under the 45×25 cm spacing (S_3), with (82.33) plants per plot. This was closely followed by 30×25 cm spacing (S_2), which recorded (81.66) plants. Broadcasting (S_1) showed a moderate population of (78.16), while the lowest plant population was observed under 60×25 cm spacing (S_4) with (74.00) plants. The present results are in support with that of [7, 8] in Maize.

Interaction (Sowing Method × Spacing)

The interaction between sowing methods and spacing treatments showed considerable variation in plant population at 30 DAS. The highest plant population was recorded in flat bed + broadcasting (B_1S_1), with 86.33 plants per plot, followed by flat bed + 45×25 cm spacing (B_1S_3) with 83.67 plants, and raised bed + 30×25 cm spacing (B_2S_2) with 83.66 plants. On the other hand, the lowest plant population was observed in flat bed + 60×25 cm spacing (B_1S_4), recording under raised bed + broadcasting (B_2S_1) with 70.00 plants. The raised bed + 60×25 cm spacing (B_2S_4) treatment also resulted in a relatively lower population (74.33 plants). The combination of flat bed sowing with broadcast spacing produced the maximum plant population at early stages, suggesting that the even seed distribution and stable soil surface enhanced seedling emergence. However, reductions in population over time were more noticeable under certain combinations involving narrower spacings and raised beds, likely due to crowding stress or physical displacement during irrigation or rain events. The present result are in accordance with that of [6, 9] in Maize.

Plant height (cm) at 30 DAS of Maize

The data on plant height of maize at 30 Days after sowing (DAS), recorded from 5 tagged plants per plot and presented in Table 2, show significant influence of sowing methods and spacing treatments, both independently and in combination.

Main Effect of Sowing Methods

Among the main plot treatments, the raised bed method (B_2) resulted in taller plants at 30 DAS, with an average height of

55.23 cm**,** compared to 50.15 cm recorded under the flat bed method (B_1). Raised bed sowing resulted in taller maize plants at early growth stages, likely due to better soil aeration and root zone conditions, which enhance nutrient uptake and early vigor. Additionally, the elevated position may improve light exposure, promoting shoot elongation. These results were in consistent with the observation with that of [5, 10, 11] in Maize.

Main Effect of Spacing

Among the sub-plot treatments, the tallest plants were observed under 30×25 cm spacing (S_2) with an average height of 55.46 cm, followed closely by 45×25 cm spacing (S_3) with 54.73 cm**.** The broadcasting method (S1) recorded the shortest plants with 48.20 cm, likely due to higher competition among closely spaced plants. The 60×25 cm spacing (S_4) showed moderate growth with a height of 52.36 cm**.** These results highlight that optimal spacing (such as 30×25 cm) promotes better plant growth by balancing resource availability and inter-plant competition. The present research agrees with an earlier reports of [11, 15] in Maize.

Interaction (Sowing Method × Spacing)

The interaction between sowing methods and spacing treatments demonstrated notable variations in plant height. The highest plant height **(**59.40 cm**)** was recorded under the combination raised bed + broadcasting (B_2S_1)**,** followed closely by raised bed + 45×25 cm spacing (B_2S_3) with 59.00 cm**.** These combinations indicate a beneficial effect of the raised bed method in promoting vertical growth, even under dense planting conditions like broadcasting. In contrast, the lowest plant height **(**45.93 cm**)** was observed in flat bed + 30×25 cm spacing (B_1S_2)**,** which deviates from the main effect trend and suggests a possible localized growth constraint under this specific treatment. Other combinations such as flat bed + 60×25 cm (B_1S_4) and raised bed + 60×25 cm (B_2S_4) also showed moderate plant heights of 52.66 cm and 52.06 cm**,** respectively. Conversely, certain flat bed combinations showed shorter plants, possibly due to soil compaction or suboptimal root development under crowded conditions. Our results also agreed with those of [11, 14, 16] in Maize.

Electrical conductivity (ECdSm^{-1})

Main Effect of Sowing Methods

The data presented in Table 3 indicate that the raised bed sowing method (B_2) recorded a lower electrical conductivity (0.39 dS m^{-1}) compared to flat bed sowing (B_1), which showed a higher value of 0.45 dS m^{-1}. This suggests that raised bed sowing helps reduce soil salinity, potentially due to improved drainage and leaching conditions. Specifically, lower electrical conductivity (0.39 dSm^{-1}) was observed in raised bed plots, suggesting reduced soil salinity levels. This could be due to improved drainage and reduced salt accumulation on the soil surface in the raised bed system. Previous studies have reported are similar to the present findings with that of [8, 10, 11] in Maize.

Main Effect of Spacing

Among the spacing treatments, the widest spacing of 60×25 cm (S_4) resulted in the lowest EC value of 0.36 dS m^{-1}. This was followed by 45×25 cm (S_3) at 0.38 dS m^{-1} and 30×25 cm (S_2) at 0.42 dS m^{-1}. Spacing treatments also demonstrated a significant impact on soil properties. The lowest EC (0.36 dSm^{-1}) was observed in the 60×25 cm spacing (S_4), followed closely by 45×25 cm spacing (S_3) at 0.38 dSm^{-1}, while the highest EC was noted in broadcasting (S_1) at 0.48 dSm^{-1}. These results imply that closer spacing or broadcasting may contribute to greater salt buildup due to limited aeration and moisture regulation. The current findings are consistent with the observations made by [5, 6, 9] in Maize.

Interaction Effect (Sowing Method × Spacing)

The interaction effect revealed that the lowest EC (0.34 dS m^{-1}) was observed in T_8 (B_2S_4 – Raised bed + 60×25 cm spacing), followed by T_7 (B_2S_3) with 0.36 dS m^{-1}. The highest EC (0.50 dS m^{-1}) occurred in T_1 (B_1S_1-Flat bed + Broadcasting).

Effect on Soil pH

Main Effect of Sowing Methods

Soil pH was slightly affected by the sowing method. Raised bed sowing (B_2) recorded a lower pH of 7.12, compared to flat bed sowing (B_1) which had a pH of 7.25.

In terms of soil pH, a similar trend was observed, with the lowest pH (7.05) recorded in S_4 and

the highest (7.30) in S_1, suggesting that denser planting can lead to slight alkalinization of the soil. Previous research also supports the results observed in our study [9, 12, 16] in Maize.

Main Effect of Spacing

The widest spacing (S_4: 60×25 cm) showed the lowest soil pH at 7.05, followed by S_3 (7.15), S_2 (7.20), and the highest pH was recorded in broadcasting (S_1) at 7.30.

Interaction Effect (Sowing Method × Spacing)

Among the interaction treatments, the lowest pH (7.00) was recorded in T_8 (B2S4 – Raised bed + 60×25 cm), while the highest pH (7.35) was observed in T_1 (B_1S_1 – Flat bed + Broadcasting). These findings are consistent with those observed in earlier studies as per [10, 12, 15] in Maize.

Effect on Organic Carbon (%)

Main Effect of Sowing Methods

Raised bed sowing (B_2) recorded a higher organic carbon content of 0.46%, compared to flat bed sowing (B_1) with 0.42% as presented in Table 3.

Main Effect of Spacing

The widest spacing (S_4: 60×25 cm) resulted in the highest organic carbon content (0.47%), followed by S3 (0.45%), S_2 (0.43%), and the lowest value was observed under broadcasting (S_1) at 0.39%. The present results coincides with those [8, 9, 11] in Maize.

Interaction Effect (Sowing Method × Spacing)

The maximum organic carbon (0.48%) was recorded in T_8 (B_2S_4 – Raised bed + 60×25 cm spacing), followed closely by T_7 (B_2S_3) and T_4 (B_1S_4). The minimum value (0.38%) was found in T_1 (B_1S_1 – Flat bed + Broadcasting).

Organic carbon levels were positively correlated with wider spacing, with the maximum OC content (0.47%) recorded in S_4 and the minimum (0.39%) in S_1. Wider spacing likely facilitates better residue decomposition and microbial activity, enhancing organic matter. These results are in agreement with those [7, 9, 10] in Maize.

Table 1: Plant Population at 30 DAS of Maize (1 Meter Square in Plot)

		Main Plot				
S. No.	Treatments	Sowing method	Plant Population at 30 DAS (1 meter square in plot)		At harvest	
1	B_1	Flat bed	11.00		10.00	
2	B_2	Raised bed	11.08		9.50	
		Sub plot treatments				
1	S_1	Broadcasting	12.00		10.83	
2	S_2	30×25cm	11.00		9.66	
3	S_3	45×25cm	10.00		8.83	
4	S_4	60×25cm	11.16		8.83	
S. No.	**Treatments**	**Treatment combination**	**Plant Population at 30 DAS (1 meter square in plot)**		**At harvest**	
1.	T_1	B_1S_1 (Flat bed+Broadcasting)	12.67		11.00	
2.	T_2	B_1S_2 (Flat bed +30×25 cm spacing)	11.00		11.00	
3.	T_3	B_1S_3 (Flat bed +45×25 cm spacing)	9.00		8.33	
4.	T_4	B_1S_4 (Flat bed +60×25 cm spacing)	11.33		10.33	
5.	T_5	B_2S_1 (Raised bed + Broadcasting)	11.43		10.66	
6.	T_6	B_2S_2 (Raised bed + 30×25 cm spacing)	11.20		9.00	
7.	T_7	B_2S_3 (Raised bed + 45×25 cm spacing)	11.10		9.33	
8.	T_8	B_2S_4 (Raised bed + 60×25 cm spacing)	11.10		9.00	
		Factors	**C.D.**	**SE(m) ±**	**C.D.**	**SE(m) ±**
		Factor A (Sowing methods)	2.12	0.65		0.54
		Factor B (Spacing)	N.S	0.92		0.77
		Factor (A×B)	1.12	1.30		1.09

Table 2: Plant height (cm) at 30 DAS of Maize (5 tagged plants per plot)

		Main Plot		
S. No.	Treatments	Sowing method	Plant height at 90 DAS (5 tagged plants per plot)	
1	B_1	Flat bed	50.15	
2	B_2	Raised bed	55.23	
		Sub plot treatments		
1	S_1	Broadcasting	48.20	
2	S_2	30×25cm	55.46	
3	S_3	45×25cm	54.73	
4	S_4	60×25cm	52.36	
S. No.	**Treatments**	**Treatment combination**	**Plant height at 90 DAS (5 tagged plants per plot)**	
1.	T_1	B_1S_1 (Flat bed+Broadcasting)	51.53	
2.	T_2	B_1S_2 (Flat bed +30×25 cm spacing)	45.93	
3.	T_3	B_1S_3 (Flat bed +45×25 cm spacing)	50.46	
4.	T_4	B_1S_4 (Flat bed +60×25 cm spacing)	52.66	
5.	T_5	B_2S_1 (Raised bed + Broadcasting)	59.40	
6.	T_6	B_2S_2 (Raised bed + 30×25 cm spacing)	50.46	
7.	T_7	B_2S_3 (Raised bed + 45×25 cm spacing)	59.00	
8.	T_8	B_2S_4 (Raised bed + 60×25 cm spacing)	52.06	
		Factors	**C.D.**	**SE(m) ±**
		Factor A (Sowing methods)	2.36	1.18
		Factor B (Spacing)	N.S	1.92
		Factor (A×B)	2.22	1.11

Table 3: Electrical conductivity ($ECdSm^{-1}$), pH and Organic carbon (OC) of Maize

		Main Plot			
S. No.	Treatments	Sowing method	EC (dSm^{-1})	pH	Organic carbon
1	B_1	Flat bed	0.45	7.25	0.42
2	B_2	Raised bed	0.39	7.12	0.46
		Sub plot treatments			
1	S_1	Broadcasting	0.48	7.30	0.39
2	S_2	30×25cm	0.42	7.20	0.43
3	S_3	45×25cm	0.38	7.15	0.45
4	S_4	60×25cm	0.36	7.05	0.47
S. No.	**Treatments**	**Treatment combination**	**EC (dSm^{-1})**	**pH**	**Organic carbon**
1.	T_1	B_1S_1 (Flat bed+Broadcasting)	0.50	7.35	0.38
2.	T_2	B_1S_2 (Flat bed +30×25 cm spacing)	0.44	7.20	0.41

3.	T_3	B_1S_3 (Flat bed +45×25 cm spacing)	0.40		7.18		0.43	
4.	T_4	B_1S_4 (Flat bed +60×25 cm spacing)	0.39		7.10		0.46	
5.	T_5	B_2S_1 (Raised bed + Broadcasting)	0.46		7.25		0.40	
6.	T_6	B_2S_2 (Raised bed + 30×25 cm spacing)	0.40		7.20		0.45	
7.	T_7	B_2S_3 (Raised bed + 45×25 cm spacing)	0.36		7.12		0.47	
8.	T_8	B_2S_4 (Raised bed + 60×25 cm spacing)	0.34		7.00		0.48	
		Factors	**C.D.**	**SE (m) ±**	**C.D.**	**SE (m) ±**	**C.D.**	**SE (m) ±**
		Factor A (Sowing methods)	1.26	0.61	0.28	0.13	1.56	0.72
		Factor B (Spacing)	1.33	0.65	0.45	0.23	1.32	0.62
		Factor (A×B)	1.38	0.69	0.38	0.27	0.89	0.45

Table 4: Available nutrients N (kg/ha), P (kg/ha) and K (kg/ha) of Maize

		Main Plot						
S. No.	**Treatments**	**Sowing method**	**N(kg/ha)**		**P(kg/ha)**		**K(kg/ha)**	
1	B_1	Flat bed	268.4		22.5		221.0	
2	B_2	Raised bed	278.6		24.2		230.5	
		Sub plot treatments						
1	S_1	Broadcasting	260.1		21.0		215.8	
2	S_2	30×25cm	270.5		23.0		222.3	
3	S_3	45×25cm	280.0		24.8		232.1	
4	S_4	60×25cm	285.5		25.3		236.4	
S. No.	**Treatments**	**Treatment combination**	**N(kg/ha)**		**P(kg/ha)**		**K(kg/ha)**	
1.	T_1	B_1S_1 (Flat bed+Broadcasting)	255.3		20.2		210.4	
2.	T_2	B_1S_2 (Flat bed +30×25 cm spacing)	265.7		22.1		219.6	
3.	T_3	B_1S_3 (Flat bed +45×25 cm spacing)	275.0		23.5		228.4	
4.	T_4	B_1S_4 (Flat bed +60×25 cm spacing)	278.5		24.1		230.6	
5.	T_5	B_2S_1 (Raised bed + Broadcasting)	265.0		21.8		221.2	
6.	T_6	B_2S_2 (Raised bed + 30×25 cm spacing)	275.2		23.8		225.0	
7.	T_7	B_2S_3 (Raised bed + 45×25 cm spacing)	285.0		26.1		235.8	
8.	T_8	B_2S_4 (Raised bed + 60×25 cm spacing)	292.5		26.5		242.0	
		Factors	**C.D.**	**SE (m) ±**	**C.D.**	**SE (m) ±**	**C.D.**	**SE(m) ±**
		Factor A (Sowing methods)	1.88	1.19	2.54	1.27	1.20	0.56
		Factor B (Spacing)	2.20	1.11	2.09	1.02	2.19	1.16
		Factor (A×B)	2.12	1.10	2.01	1.99	2.38	1.17

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